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Detailed Cost Estimate of Reference Residential Photovoltaic Designs

Roberta S. Palmer, David A. Penasa, Michael G. Thomas

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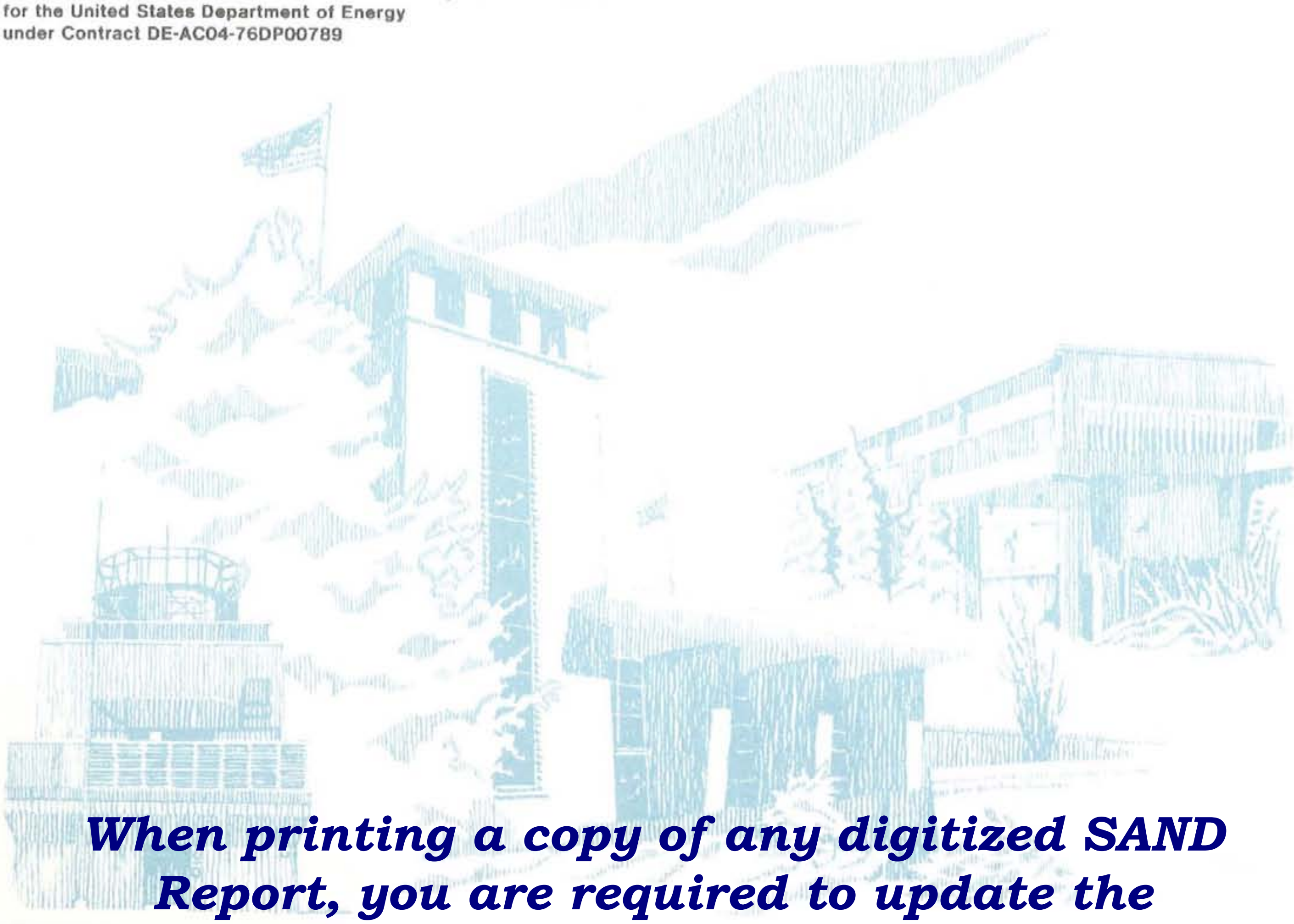

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Detailed Cost Estimate of Reference Residential Photovoltaic Designs

Roberta S. Palmer
E/E '2000 Engineering, Inc.
Albuquerque, NM 87198

David A. Penasa
Uhl & Lopez Engineers, Inc.
Albuquerque, NM 87198

Michael G. Thomas
Photovoltaic Systems Development Division
Sandia National Laboratories
Albuquerque, NM 87185

Abstract

This report presents estimated installation costs for four reference residential photovoltaic designs. Installation cost estimates ranged from \$1.28 to \$2.12/W_p for arrays installed by union labor (4.1 to 6.07 kW_p-systems), and from \$1.22 to \$1.83 W_p for non-union installations. Standoff mounting was found to increase costs from \$1.63/W_p to \$2.12/W_p for a representative case, whereas 25 kWh of battery storage capacity increased installation costs from \$1.44/W_p to \$2.08/W_p. Overall system costs (union-based) were \$6,000 – \$7,000 for a 4.1 kW array in the northeast, to ≈\$9,000 for a 6.07 kW_p array in the southwest. This range of installation costs, ≈\$1 – \$2/W_p (in 1980 dollars), is representative of current installation costs for residential PV systems. Any future cost reductions are likely to be small and can be accomplished only by optimization of mounting techniques, module efficiencies, and module reliability <u>in toto</u>.

PREFACE

This report contains detailed cost estimates of four residential photovoltaic designs prepared by the General Electric Company, Energy Systems and Technology Division. The procedures and estimates were taken from final contractor reports prepared by Uhl and Lopez Engineers, Inc. and E/E's 2000 Engineering, Inc., both of Albuquerque, New Mexico.

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I. Introduction

The cost of a photovoltaic (PV) system includes purchase of the PV hardware and power conditioner; installation, which includes wiring and the structure; and operation and maintenance. This report examines the estimated installation costs for a number of residential PV system designs.

A. Background

In February, 1982 the General Electric Company, Energy Systems and Technology Division completed a program entitled "Detail Residential System Reference Design Study".[1-4] The program produced six detailed designs for PV systems, which included sufficient information to obtain detailed installation cost estimates. Four of these designs were subsequently costed independently by two firms, Uhl & Lopez Engineers, Inc., and E/E '2000 Engineering, Inc., both of Albuquerque, New Mexico, under contract to Sandia. This report describes the installation costs associated with the designs, several problems associated with installation, and suggestions for further improvement.

The report is divided into three major sections: the Cost Estimate Procedures, Detailed Cost Estimates, and Discussion and Recommendations. The procedures and estimates in this report were taken from final contractor reports prepared by E/E '2000 and D. A. Penasa of Uhl & Lopez. The estimation procedures were somewhat different. Comparisons in $\$/W_p$ are provided in the discussion. Recommendations provided are based upon contractor comments, the Residential Program at SNLA, and the Systems Definition Project at SNLA.

B. Reference Residential Photovoltaic Designs

A description of the four designs is presented in outline form as follows.

I. The Design of a Photovoltaic System with On-Site Storage for a Southwest All-Electric Residence (Figure 1).

A. <u>House Description</u>:

1. The house design is a single-story residence of new construction for the Southwest region of the country.

2. The design includes passive solar and energy conservation features projected for 1986.

3. There are 1,600 ft^2 of living area with 1,120 ft^2 of south-facing roof area.

4. The house is all-electric with a 3-ton heat pump and electric hot water heater.

5. The site layout includes a detached garage with a lot area between 1/6 and 1/4 acre.

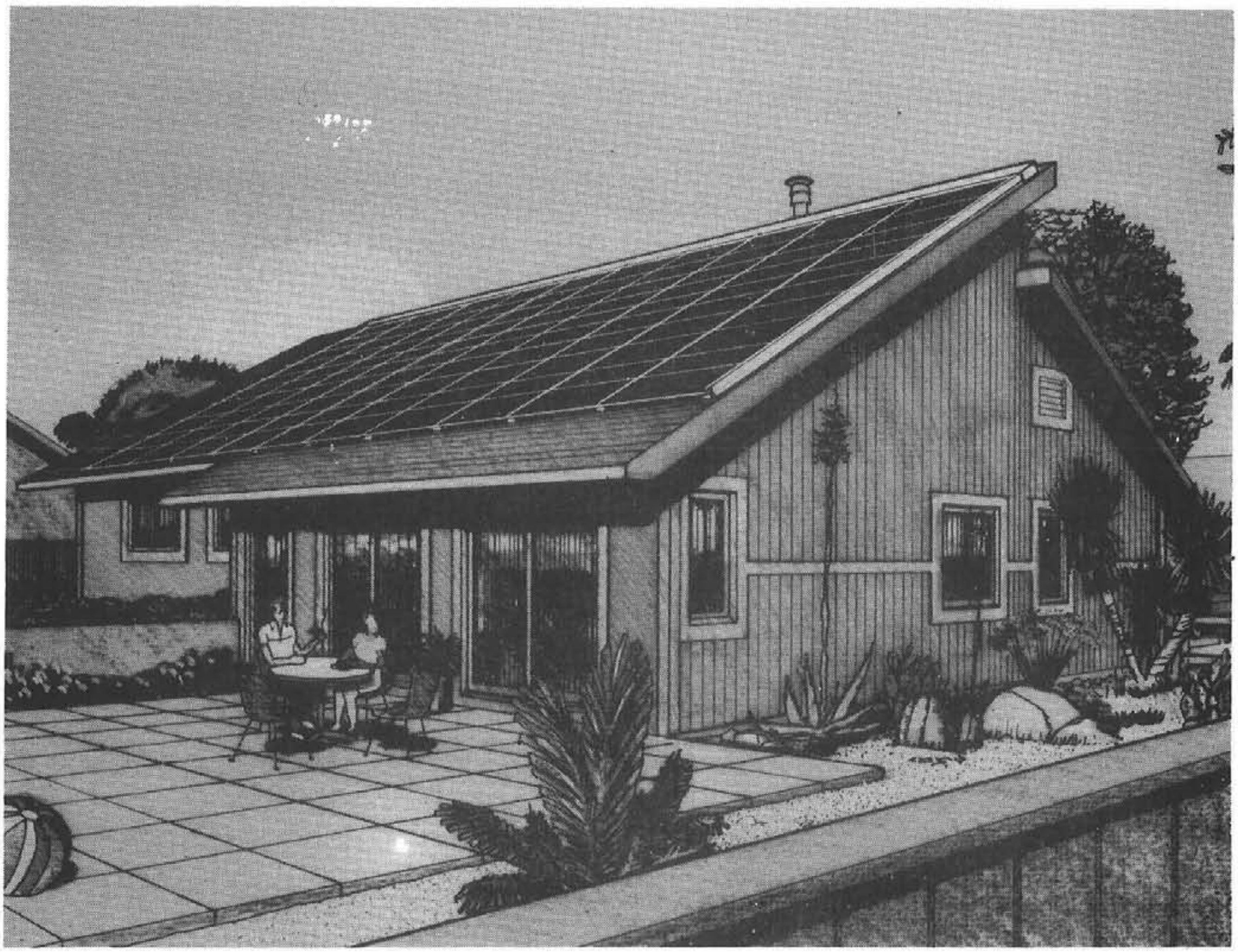

Figure 1. Southwest Residence (1,600 ft^2) with a 6.07-kW Standoff PV System and On-Site Storage

B. <u>PV System Description:</u>

1. The system is a 6.07-kW standoff, grid connected array using 100 Solarex Block IV intermediate load modules.

2. The modules are mounted on wood 2" x 4" standoffs with conventional asphalt shingles beneath the modules.

3. The PV module frame fits into aluminum clips mounted to the standoffs and attaches to the clips by sheet metal screws. Electrical interconnections between modules are made by cables with plug-in connectors.

4. The battery storage subsystem includes a 25-kWh lead acid battery to store PV-generated power. A battery charge controller controls the bus voltage.

5. The power conversion subsystem (PCS) employs a 6-kVA line-commutated inverter to convert PV generated power to ac. A 10-kVA single-phase isolation transformer matches ac supply voltage to the load.

6. The system operation is parallel and synchronized with the utility, without feedback.

7. Excess generated power is shunted to ground.

II. The Design of a Photovoltaic System for a Passive-Design Northeast All-Electric Residence

A. <u>House Description:</u>

1. The house is a two-story residence with a basement of new construction for the Northeast region of the country (Figure 2).

2. The design includes passive solar and energy conservation features projected in 1986.

3. There are 1,690 ft^2 of living area with a 96 ft^2 greenhouse and 614 ft^2 of south facing roof area.

4. The house is all-electric with a 2-1/2 ton heat pump and electric hot water heater.

5. The site layout has a detached garage with a lot area of 1/4 acre.

B. <u>P-V System Description:</u>

1. The system is a 4.1 kW direct mounted array using 56 General Electric shingle PV modules.

2. The modules are direct-mounted on top of the roofing felt and plywood roof sheathing.

3. The modules are installed by an overlapping procedure similar to conventional shingles. Each shingle module is electrically interconnected by two flat conductor cables. Standard roofing nails are used for attachment to the roof.

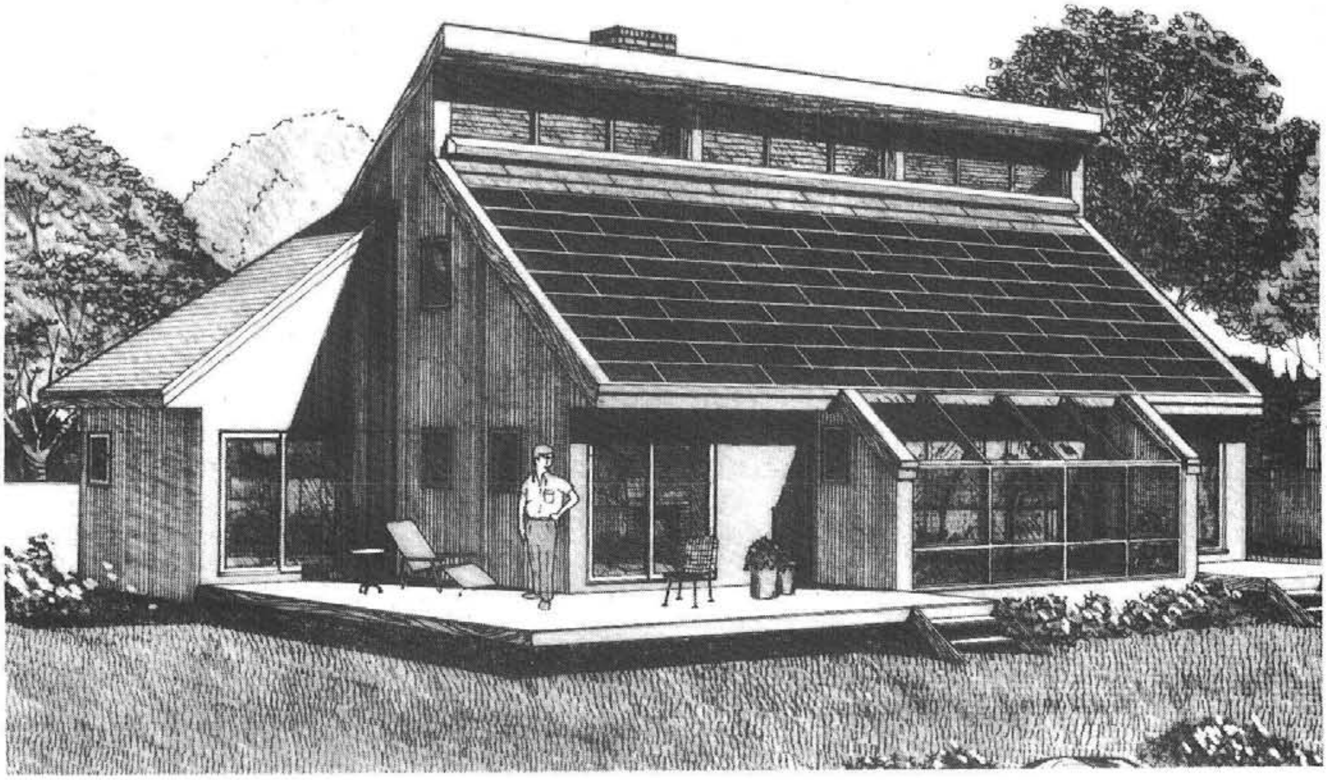

Figure 2. Passive-Design Northeast Residence (1,690 ft^2) with a 4.1 kW Direct Mount PV System

4. The power conversion subsystem (PCS) uses a 4-kVA line-commutated maximum power tracking inverter to convert dc generated power to ac. A 5-kVA single-phase isolation transformer is used to match ac supply voltage to the load.

5. The system is parallel to and synchronized with the utility.

6. Excess generated power is fed back to the utility.

III. The Design of a Photovoltaic System for a Temperate Climate All-Electric Residence

A. <u>House Description:</u>

1. The house design is a single-story residence of new construction for a temperate climate region, Figure 3.

2. The design includes passive solar and energy conservation features projected for 1986.

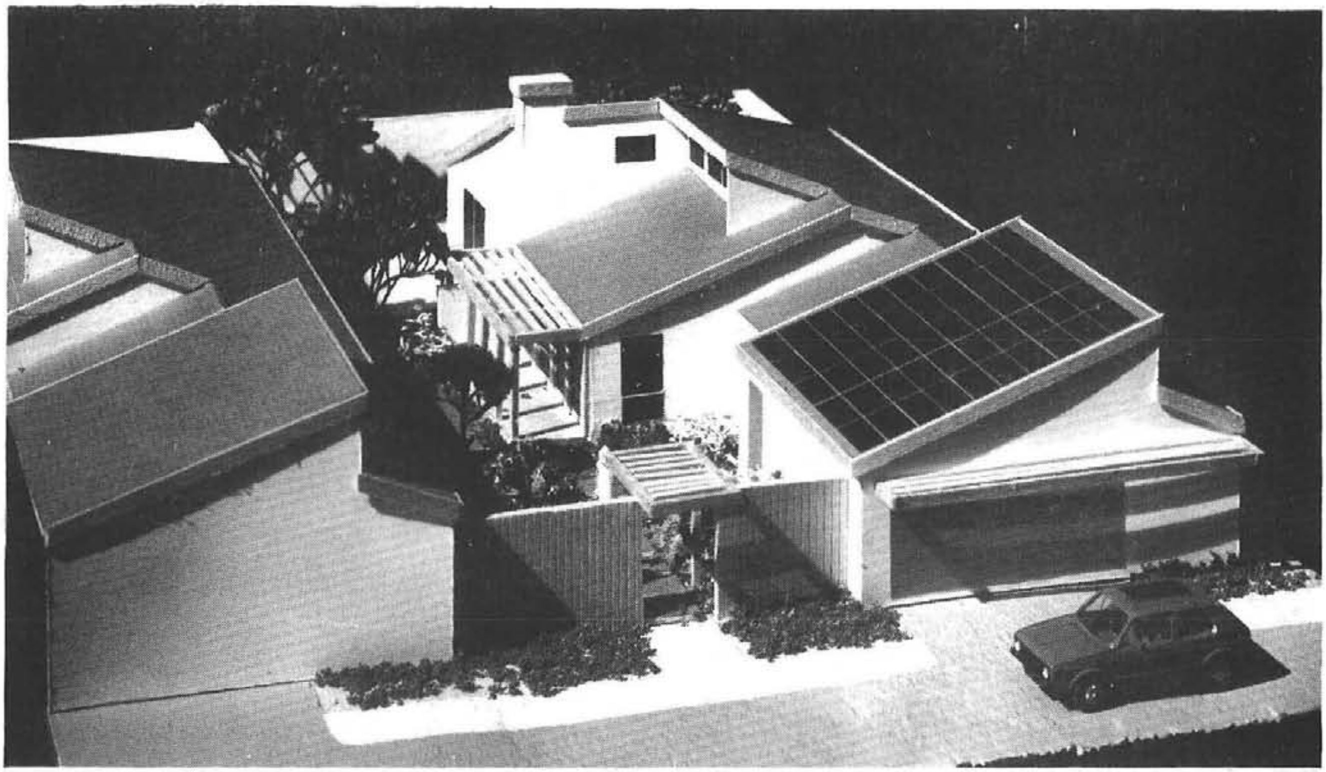

Figure 3. Temperate Climate Residence (1,530 ft^2) with a 4.29 kW Integral-Mount PV System

3. The design has 1,530 ft^2 of living space and includes a two-car garage with 477 ft^2 of garage roof area available for mounting the solar array.

B. PV System Description:

1. The system is a 4.29 kW array using 50 Solarex PV modules similar to the Block IV residential module but with sealant strips attached for mounting.

2. The array consists of PV modules and mounting accessories which may be used either as an integral mount or as a standoff mount.

3. The modules are mounted on a series of channel supports which can be placed on the roof truss system for an integral mount or on the shingled roof for a standoff mount. An overlapping seam is used between modules to shed water. Electrical connections are made with cables equipped with plug-in connectors.

4. The power conversion subsystem uses a 4-kVA maximum power tracking inverter to convert dc generated to ac, and to match ac supply voltage and load.

5. The system is parallel to and synchronized with the utility.

6. Excess generated power is fed back to the utility.

IV. The Design of a Photovoltaic System for a Southeast All-Electric Residence

A. House Description:

1. The house design is a single-story residence of new construction for the Southeast region of the country (Figure 4).

2. The design includes passive solar and energy conservation features projected in 1986.

3. The design has 1,736 ft^2 of living area and 992 ft^2 of south facing roof area.

4. The house is all-electric with a 3-ton heat pump and electric hot water heater.

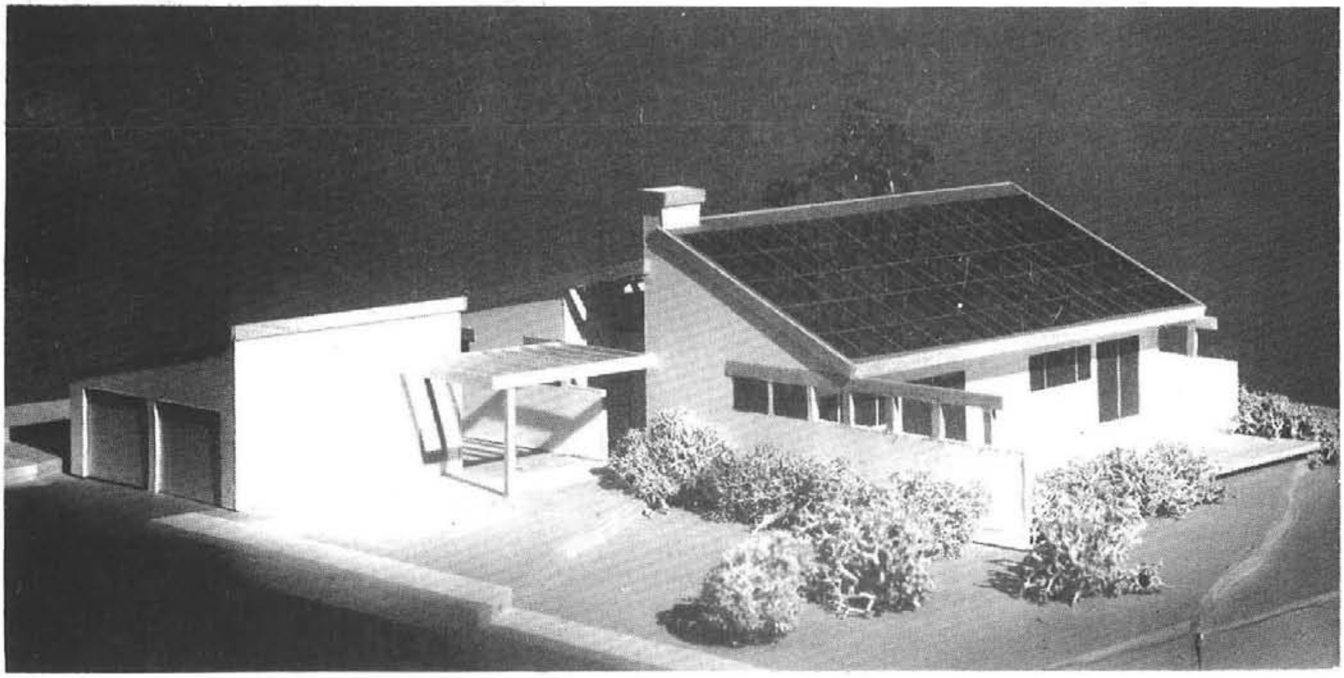

Figure 4. Southeast Residence (1,736 ft^2) with a 5.6-kW Integral Mount PV Systems

B. P-V System Description:

1. The system is a 5.6-kW NCT array using 98 Solarex Block IV intermediate load PV modules incorporated into an integral mount design.

2. The modules and mounting extrusions are secured on the roof rafters and the horizontal roof purlins.

3. Mounting extrusions are attached to the rafters with screws. The modules are then bolted to the mounting extrusions. This compresses an elastomeric material to form a seal.

4. Electrical connections are made with cables equipped with plug-in connectors.

5. The power conversion subsystem (PCS) employs a 6-kVA self-commutated maximum power tracking inverter to convert dc generated power to ac and to match ac supply voltage to the load.

6. The system operation is parallel and synchronized with the utility.

7. Excess generated power is fed back to the utility.

II. Cost Estimation Procedure

Two estimates were prepared for each design, one with non-union labor costs and the other with union labor costs. The estimates include only the cost of installing mounting brackets, labor and material for the arrays, the battery system (where applicable), and the power conditioning system; they do not include the cost of the arrays themselves, the battery system or the power conditioning system.

For estimate preparation, the PV system was divided into the following categories:

1. Installation of Photovoltaic Array
2. Installation of Power Conditioning System
3. Installation of Battery Storage System (if applicable)
4. Power Wiring

Estimation procedures varied somewhat between the two firms. Procedures and estimates from both firms will be presented and discussed.

A. Method Used by E/E '2000, Inc.

For estimating purposes, four specific areas were selected: Southwest - Albuquerque, New Mexico; Northeast - Buffalo, New York; Southeast - Charlotte, North Carolina; and Temperate Climate - Oakland, California.

Non-union labor costs were estimated by requesting, from non-union subcontractors in each area, information on hourly labor costs, percentage of overhead and profit, and benefits offered to employees. Several responses from non-union subcontractors in Albuquerque were received, but very few were received from non-union subcontractors in other areas, despite initial telephone contact, initial letter, follow-up telephone contact, and follow-up letter in some cases. To calculate the hourly charges for a two-man crew at non-union wages, the rate information received from the Albuquerque area subcontractors were averaged. To estimate union labor costs, information on journeyman and apprentice hourly wages and contributions to benefit funds were requested from local unions in each area . All the local unions contacted furnished the requested information. The non-union and union rates for Albuquerque were compared to devise a ratio for calculating non-union rates for the other three areas. Information received from the local unions was added to union subcontractors' overhead and profit (see Table 1 for breakdown) to estimate hourly rates for union subcontractors. Note: hours shown on the estimates are for crew hours (two-man crews), not man hours.

The cost of materials was estimated using several methods. Wiring, conduit, boxes, and miscellaneous materials needed for wiring installation were priced from the National Price Service manual. Pricing information for lumber, flashing, nuts and bolts was requested from area lumber yards. Drawings were sent to Joseph T. Ryerson and Son, Inc. for prices on the aluminum extrusions and rolled steel mounting brackets.

Table 1
CREW HOUR COST COMPARISONS BY AREA

AREA COMPARISONS
2-MAN CREW HOUR COSTS

CITY	UNION	NON-UNION
Albuquerque, New Mexico	$ 39.50	$ 36.00
Buffalo, New York	$ 43.80	$ 40.00
Charlotte, North Carolina	$ 28.50	$ 26.00
Oakland, California	$ 65.40	$ 60.00

B. Method used by Uhl & Lopez

These estimates were prepared in accordance with the Sandia Plant Engineering Cost Estimating Manual[7] using the quantity survey method. Separate detailed cost estimates were prepared for each reference residential design using Davis-Bacon (Union) wage rates and non-Davis-Bacon (Non-Union) wage rates so that cost differences could be observed. Locations used were Albuquerque, NM, Boston, MA, Santa Barbara, CA, and Miami, FL.

Base union wage rates, including fringes, were obtained from the 1982 edition of "Building Construction Cost Data,"[5] Robert Snow Means Company, Inc. Values used were carpenter rates ($17/hr) for installation of the PV Array and electrician rates ($19.40/hr) for the remainder of the work.

Base non-union wage rates, including fringes, were obtained from discussions with several local (Albuquerque) non-union electrical contractors and solar system specialty firms. Values used were $13/hr for carpenter rates and $16/hr for electrician rates.

Wage rates were adjusted for the specific project location by the use of a "City Cost Index" multiplier obtained from the above cost data reference. Weighted project average values were used to reflect an average cost difference between cities for work involving both the carpenter and electrical trades.

Table 2 below indicates the multipliers used:

Table 2
CITY COST INDEXES - LABOR

Albuquerque, NM	89.0
Boston, MA	94.1
Santa Barbara, CA	117.4
Miami, FL	85.4

The amount of time (in hours) required to install specific construction items was obtained from the 1982 editions of "Building Construction Cost Data"[5] and "Mechanical & Electrical Cost Data,"[6] both by the Robert Snow Means Company, Inc. Installation by experienced tradesmen is assumed in these references. Labor units, i.e. the time required to perform a specific task, were assumed to be the same for both union and non-union labor, and among project locations.

Material costs for standard construction items were also obtained from References 5 and 6. Material costs for custom materials or non-standard building construction items were obtained by talking to local electrical/electronic supply houses and sheet metal shops.

Costs included in the reference designs for items such as extruded aluminum supports and elastomeric materials, were based upon expected costs assuming that these items would be custom made in mass quantity to supply stock for solar system retailers and manufacturers.

Material costs were adjusted for a specific project location by the use of a "City Cost Index" multiplier obtained from the above cost data references. Weighted project average values were used to reflect an average cost difference between cities for both building and electrical materials.

Table 3 below indicates the multipliers used:

Table 3
CITY COST INDEXES - MATERIAL

Albuquerque, NM	99.7
Boston, MA	106.4
Santa Barbara, CA	103.6
Miami, FL	96.0

III. Detailed Cost Estimates

In this section, each design will be described by a System One-Line Diagram. A summary cost sheet from the two contractor estimates will also be provided along with a brief written description. Comparisons are provided in Section IV. A major procedural difference contained in these estimates is that Uhl & Lopez did not include the installation of wiring in the array and PCS costs. The E/E '2000 estimates included the wiring installation costs, specific to connection to the subsystem (except as noted for the Northeast Residence). Therefore, direct comparisons between the Uhl & Lopez and E/E '2000 estimates should be deferred to Section IV. The estimates are given in the two different forms to allow the reader to directly analyze the merit of either procedure.

A. Southwest Residence

A breakdown of the system is shown in the One-Line Diagram, Figure 5.

1. E/E '2000 Estimate (See Table 4) --The solar array consists of 100 modules with an output of 6.07 kW_p. Installation cost for the array is \$6,502 at union wages and \$6,274 at non-union wages.

The battery system has a capacity of 25 kWh. The cost of installing the battery system is \$2,411 at union wages and \$2,385 at non-union wages.

The power conditioning system employs a 6-kVA line commutated inverter. Installation of the power conditioning system costs \$1,301 at union wages and \$1,249 at non-union wages.

Wiring for the photovoltaic system included 250 feet of conduit. Conduit footage was used to calculate wiring costs. Wiring costs \$972 at union wages and \$930 at non-union wages.

The total cost for installation and wiring of the entire photovoltaic system, including the installation and wiring cost of the battery system, at union wages is \$11,187 which is \$1,843 a kilowatt at a peak of 6.07 kW. At non-union wages, the cost is \$10,839 which is \$1,786 a kilowatt at the peak. The total cost for installing and

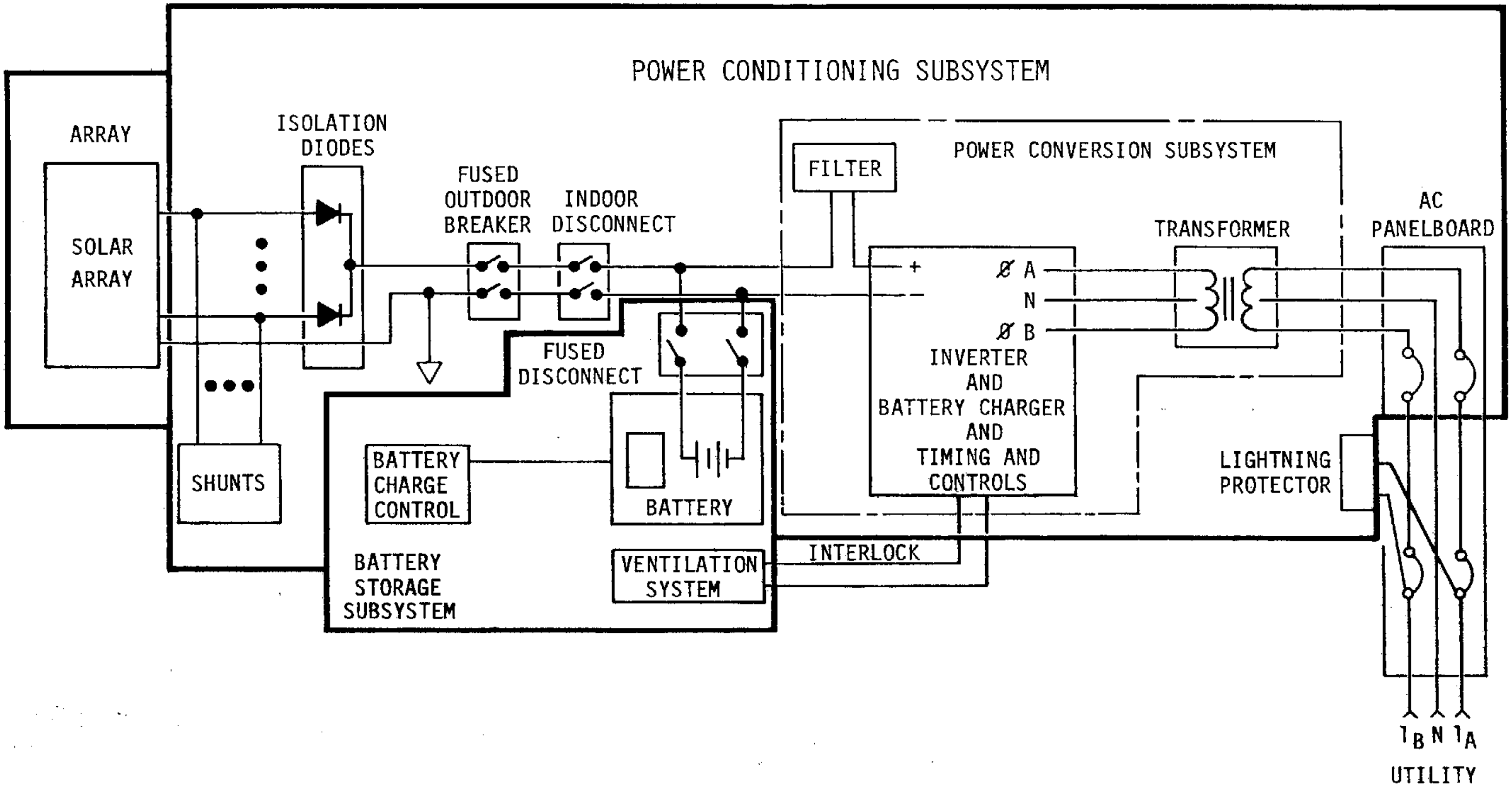

FIGURE 5. SOUTHWEST SYSTEM ONE-LINE DIAGRAM.

Table 4

E/E '2000 COST ESTIMATE

RESIDENCE: SOUTHWEST All electric with on-site storage 25 kWh (Albuquerque, NM)

ARRAY

UNION		NON-UNION
$2,577	LABOR	$2,349
2,617	MATERIALS	2,617
1,308	50% MATERIAL MARK-UP	1,308
$6,502	TOTAL	$6,274

POWER CONDITIONING

UNION		NON-UNION
$ 583	LABOR	$ 531
479	MATERIALS	479
239	50% MATERIAL MARK-UP	239
$1,301	TOTAL	$1,249

BATTERY

UNION		NON-UNION
$ 296	LABOR	$ 270
1,410	MATERIALS	1,410
705	50% MATERIAL MARK-UP	705
$2,411	TOTAL	$2,385

WIRING

UNION		NON-UNION
$ 474	LABOR	$ 432
332	MATERIALS	332
166	50% MATERIAL MARK-UP	166
$ 972	TOTAL	$ 930

$11,186	GRAND TOTAL	$10,838

wiring the photovoltaic system, not including the installation and wiring cost of the battery system, is $8,776 at union wages which is $1,445 per kilowatt and $8,454 at non-union wages which is $1,393 per kilowatt.

2. Uhl & Lopez Estimate (See Table 5) -- The material basecost for the 6.07 kW_p array installation is $991 including a 25 percent mark-up (1.25 multiplier). The labor cost for the installation is $3,154 based upon union labor (1.35 multiplier). With non-union labor, the cost is reduced to $2,411. The array installation cost does not include wiring.

The cost of the PCS installation for labor only is $624 with union labor or $514 with non-union labor. This estimate is for placement of the PCS without the array-PCS wiring. The cost of the power wiring is $1,195. The labor associated with wiring of the array is the second-largest cost, $2,755 using union labor, incurred in the installation.

The total cost for the installation without storage is $8,719 at union scale and $7,383 with non-union wages. Costs with storage are $12,644 and $11,052 respectively.

B. Northeast Residence

A breakdown of the System is shown in the One-Line Diagram, Figure 6.

1. E/E '2000 Estimate (See Table 6) -- The solar array consists of 52 full-shingle modules and 8 half-shingle modules with a rated peak output of 4.1 kW. Installation of the array, including wiring, costs $3,382 at union wages and $3,264 at non-union wages.

The power conditioning system converts dc to ac with a 4 kVA line commutated maximum power tracking inverter. The cost of installing the power conditioning system, not including wiring, is $1,984 at union wages and $1,909 at non-union wages ($496 per kVA at union wages and $477 per kVA at non-union wages for a 4KVA inverter).

The wiring for the power conditioning system consists of 81 feet of conduit. Conduit footage was used to calculate wiring costs. Cost

Table 5
UHL & LOPEZ

Residence: Southwest All-Electric with Battery Storage (Albuquerque, NM)

	UNION				NON-UNION			
	MATERIAL		LABOR		MATERIAL		LABOR	
	BASE COST	LOADED COST	BASE COST	LOADED COST	BASE COST	LOADED COST	BASE COST	LOADED COST
Array	$ 793	$ 991	$2,336	$3,154	$ 793	$ 991	$1,786	$2,411
PCS	0	0	462	624	0	0	381	514
Wiring	956	1,195	2,041	2,755	956	1,195	1,683	2,272
Storage	1,973	2,466	1,081	1,459	1,973	2,466	891	1,203
Sub-Totals		$4,652		$7,992		$4,652		$6,400
Grand Total			$12,644				$11,052	

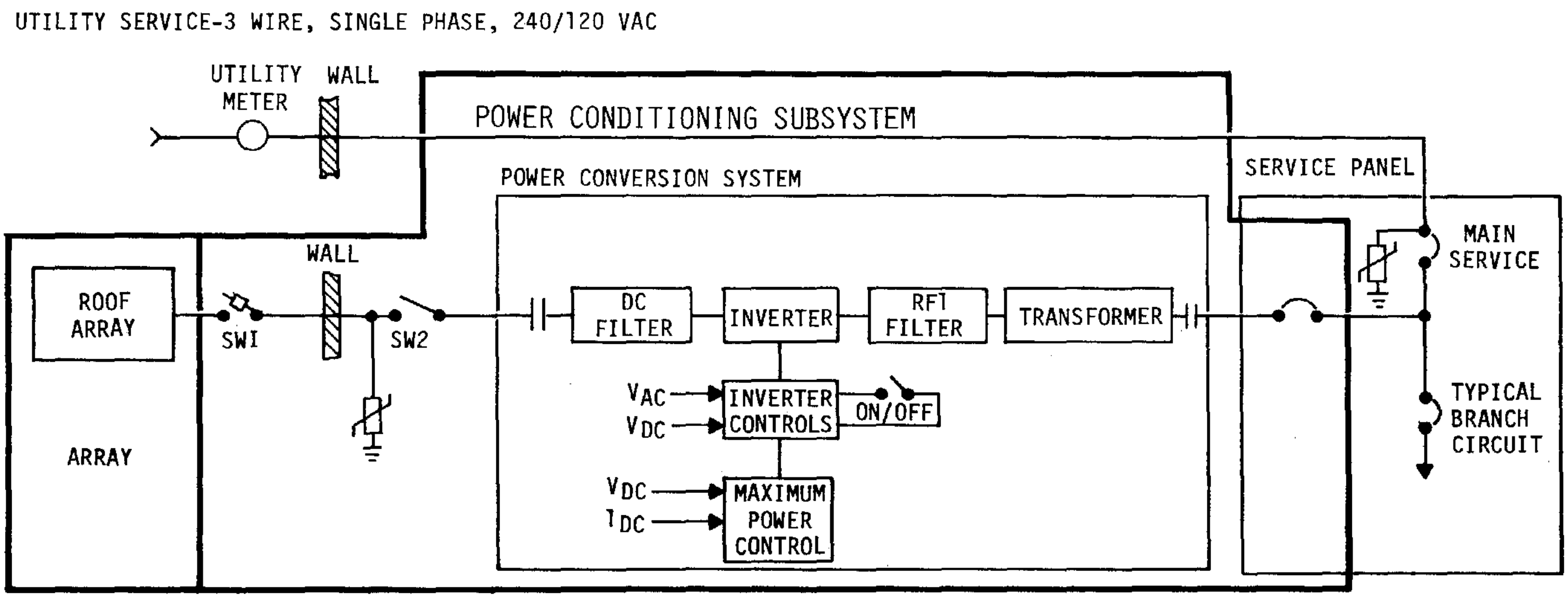

FIGURE 6. NORTHEAST SYSTEM ONE-LINE DIAGRAM.

Table 6

E/E '2000 COST ESTIMATE

RESIDENCE: NORTHEAST All electric, Passive Design (Buffalo, NY)

ARRAY

UNION		NON-UNION
$1,357	LABOR	$1,240
1,349	MATERIALS	1,349
674	50% MATERIAL MARK-UP	674
$3,380	TOTAL	$3,263

POWER CONDITIONING

UNION		NON-UNION
$ 865	LABOR	$ 790
746	MATERIALS	746
373	50% MATERIAL MARK-UP	373
$1,984	TOTAL	$1,909

WIRING

UNION		NON-UNION
$ 438	LABOR	$ 400
234	MATERIALS	234
117	50% MATERIAL MARK-UP	117
$ 789	TOTAL	$ 751

$ 6,153	GRAND TOTAL	$5,923

for wiring is $789 at union wages and $751 at non-union wages. Cost per foot is $9.74 at union wages and $9.27 at non-union wages.

For installation and wiring of the entire photovoltaic system, the total cost is $6,155 at union wages or $1,501 a kilowatt at a peak of 4.1 kW. The cost is $5,924 at non-union wages or $1,445 a kilowatt at the peak.

2. Uhl & Lopez Estimate (See Table 7) -- The cost of installation of the 4.1-kW_p array in Boston at non-union wages is $1,094 or $1,340 at union wages. The PCS installation is $554 at union scale and $456 at non-union scale. The wiring for this design is expensive at $3,796, greater than the total labor costseven at union wages--$2,851. The total cost for this design is $6,936 at union scale and $6,374 with non-union wages.

C. Southeast Residence

A breakdown of the system is shown in the One-Line Diagram, Figure 7.

1. E/E '2000 Estimate (See Table 8) -- The solar array consists of 98 modules with a peak output of 5.6 kW. At union wages, the cost of installing and wiring the array is $5,567 and at non-union wages, the cost is $5,252. Cost per kilowatt is $994 at union wages and $937 at non-union wages.

The power conditioning system employs a 6-kVA self-commutated maximum power tracking inverter. Installation of the power conditioning system costs $724 at union wages and $702 at non-union wages. At 6 kVA, the cost per kVA is $120 at union wages and $117 at non-union wages.

Wiring the photovoltaic system involves 165.5 feet of conduit. To calculate wiring costs, conduit footage was used. Wiring cost is $895 at union wages and $863 at non-union wages. Cost per foot is $5.41 at union wages and $5.21 at non-union wages.

The total cost for installation and wiring the entire photovoltaic system is $7,186 at union wages, which is $1,283 a kilowatt at a kW_p of 5.6. The cost is $6,817 at non-union wages, which is $1,217 a kilowatt at the peak.

Table 7

UHL & LOPEZ

Residence: Northest All-Electric (Boston, MA)

	UNION				NON-UNION			
	MATERIAL		LABOR		MATERIAL		LABOR	
	BASE COST	LOADED COST	BASE COST	LOADED COST	BASE COST	LOADED COST	BASE COST	LOADED COST
Array	$ 217	$ 289	$ 751	$1,051	$ 217	$ 289	$ 575	$ 805
PCS	0	0	396	554	0	0	326	456
Wiring	2,854	3,796	890	1,246	2,854	3,796	734	1,028
Sub-Totals		$4,085		$2,851		$4,085		2,289
Grand Total	$ 6,936				$ 6,374			

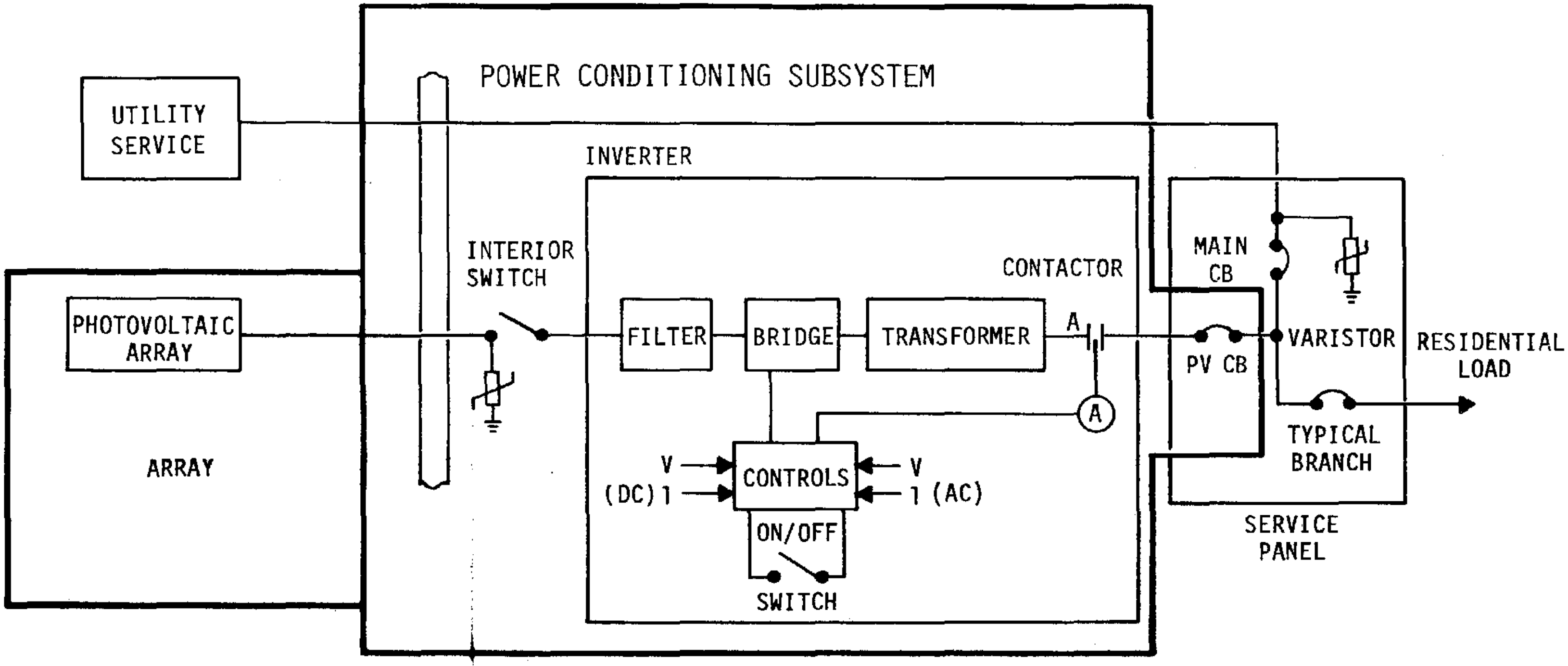

FIGURE 7. SOUTHEAST SYSTEM ONE-LINE DIAGRAM.

Table 8

E/E '2000 COST ESTIMATE

RESIDENCE: SOUTHEAST All electric, (Charlotte, NC)

ARRAY

UNION		NON-UNION
$3,591	LABOR	$3,276
1,317	MATERIALS	1,317
659	50% MATERIAL MARK-UP	659
$5,567	TOTAL	$5,252

POWER CONDITIONING

UNION		NON-UNION
$ 256	LABOR	$ 234
312	MATERIALS	312
156	50% MATERIAL MARK-UP	156
$ 724	TOTAL	$ 702

WIRING

UNION		NON-UNION
$ 370	LABOR	$ 338
350	MATERIALS	350
175	50% MATERIAL MARK-UP	175
$ 895	TOTAL	$ 863

$7,186	GRAND TOTAL	$ 6,817

2. Uhl & Lopez Estimate (See Table 9) -- The cost of array installation for this 5.6 kW_p array is evenly distributed between materials, $2,985, and labor, $2,841, at union wage scale, or $2,173 at non-union wages. PCS installation is $512 at union and $422 at non-union wages. Wiring costs are significantly lower than the northeast direct mount at $1,836 at union scale and $1,617 at non-union wages. Total cost of this system is $8,176 and $7,197 at union and non-union wages respectively ($1.62/$W_p$ to $1.29 W_p).

D. Temperate Climate

A breakdown of the System is shown in the One-Line Diagram in Figure 8.

1. E/E '2000 Estimate (See Table 10) -- The solar array consists of 50 modules with a rated output peak of 4.3 kW. The cost for installing the array is $8,265 at union wages and $7,919 at non-union wages. Cost per kilowatt is $1,921 at union wages and $1,841 at non-union wages.

The power conditioning system uses a 4-kVA maximum power tracking inverter. Installation cost for the power conditioning system is $928 at union wages and $884 at non-union wages. At 4 kVA the cost is $232 per kVA at union wages and $220 per kVA at non-union wages.

Wiring the entire photovoltaic system employs 60.5 feet of conduit. Conduit footage was used for calculating wiring costs. At union wages the wiring costs $670 and at non-union wages the wiring costs $638. The cost per foot at union wages is $11.07 and at non-union wages is $10.54.

The total cost for installation and wiring of the entire photovoltaic system is $9,863 at union wages or $2,294 per kilowatt at a peak of 4.3 kW. The cost is $9,441 at non-union wages or $2,195 per kilowatt at the peak.

2. Uhl & Lopez Estimate -- The design for the Temperate Climate residence included the option of integral or stand-off mount (see Tables 11 and 12). Both options were costed. For the stand-off mount, the array installation costs were $6,811 at union wages and $5,873 at non-union wages. The integral mount installation costs were significantly less, $4,614 and $3,941.

Table 9

UHL & LOPEZ

Residence: Southeast All-Electric (Miami, FL)

	UNION				NON-UNION			
	MATERIAL		LABOR		MATERIAL		LABOR	
	BASE COST	LOADED COST	BASE COST	LOADED COST	BASE COST	LOADED COST	BASE COST	LOADED COST
Array	$2,467	$2,985	$2,152	$2,841	$2,467	$2,985	$1,646	$2,173
PCS	0	0	388	512	0	0	320	422
Wiring	476	576	956	1,262	476	576	789	1,041
Sub-Totals		$3,561		$4,615		$3,561		$3,636
Grand Total			$8,176				$7,197	

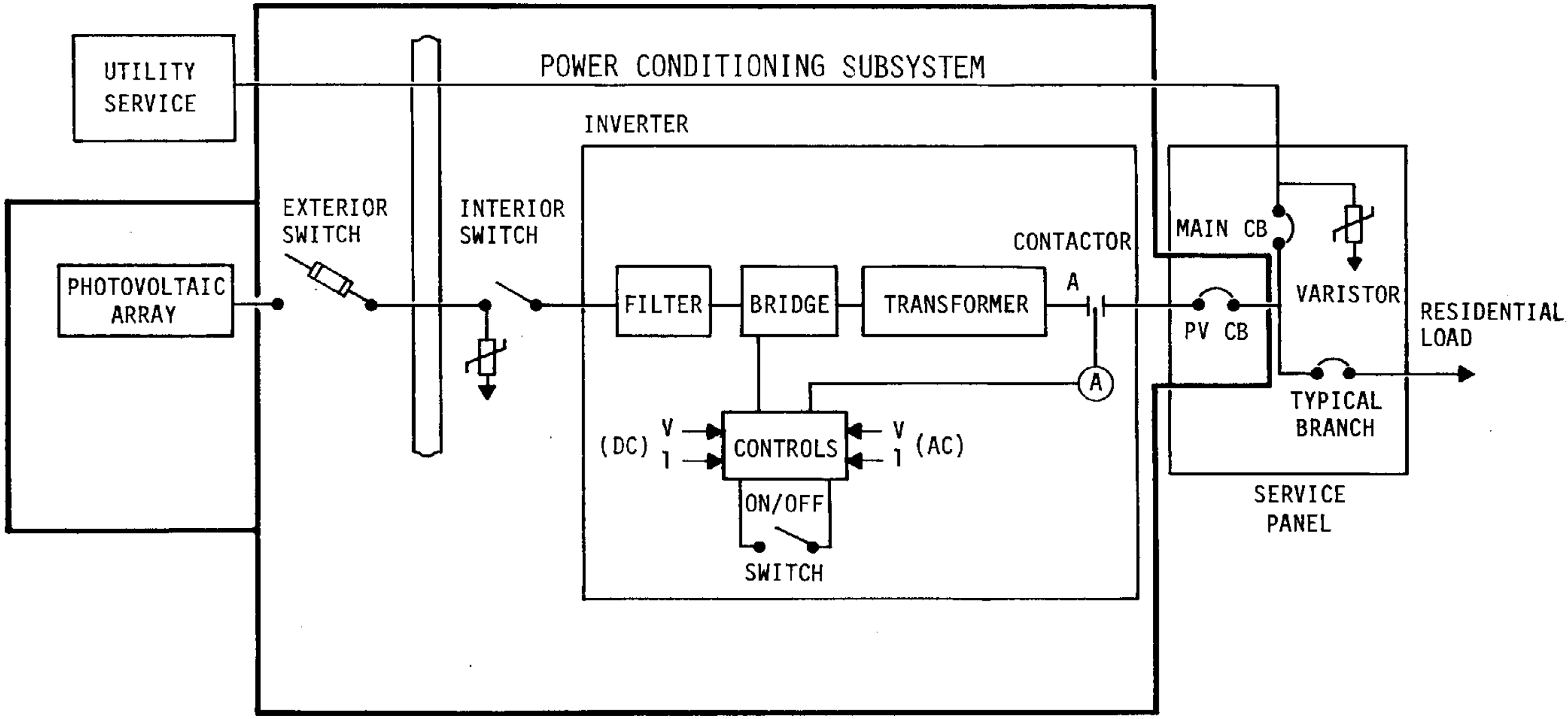

FIGURE 8. TEMPERATE CLIMATE SYSTEM ONE-LINE DIAGRAM.

Table 10

E/E '2000 COST ESTIMATE

RESIDENCE: TEMPERATE CLIMATE (Integral Mount, Oakland, CA 4.3 kW_p)

ARRAY

UNION		NON-UNION
$4,186	LABOR	$3,840
2,719	MATERIALS	2,719
1,360	50% MATERIAL MARK-UP	1,360
$8,265	TOTAL	$7,919

POWER CONDITIONING

UNION		NON-UNION
$ 539	LABOR	$ 495
259	MATERIALS	259
130	50% MATERIAL MARK-UP	130
$ 928	TOTAL	$ 884

WIRING

UNION		NON-UNION
$ 392	LABOR	$ 360
185	MATERIALS	185
93	50% MATERIAL MARK-UP	93
$ 670	TOTAL	$ 638

$ 9,863	GRAND TOTAL $/JOB	$9,441

Table 11

UHL & LOPEZ

Residence: Temperate Climate All-Electric, Integral Mount (Santa Barbara, CA)

	UNION				NON-UNION			
	MATERIAL		LABOR		MATERIAL		LABOR	
	BASE COST	LOADED COST	BASE COST	LOADED COST	BASE COST	LOADED COST	BASE COST	LOADED COST
Array	$1,350	$1,755	$1,743	$2,859	$1,350	$1,755	$1,333	$2,186
PCS	0	0	388	636	0	0	320	525
Wiring	440	572	712	1,168	440	572	587	963
Sub-Totals		$2,327		$4,663		$2,327		$3,674
Grand Total			$ 6,990				$ 6,001	

Table 12

UHL & LOPEZ

Residence: Temperate Climate All-Electric, Stand-Off Mount (Santa Barbara, CA)

	UNION				NON-UNION			
	MATERIAL		LABOR		MATERIAL		LABOR	
	BASE COST	LOADED COST	BASE COST	LOADED COST	BASE COST	LOADED COST	BASE COST	LOADED COST
Array	$2,172	$2,824	$2,431	$3,987	$2,172	$2,824	$1,859	$3,049
PCS	0	0	388	636	0	0	320	525
Wiring	422	549	670	1,099	422	549	552	905
Sub-Totals		$3,373		$5,722		$3,373		$4,479
Grand Total			$ 9,095				$ 7,852	

PCS costs were the same, but wiring costs were slightly lower for the stand-off case: $1,648 at union wages and $1,454 at non-union wages as compared to $1,740 and $1,535 for the integral mount.

Overall costs for the standoff were $9,095 at union wages and $7,852 at non-union wages. Overall costs for the integral mount were significantly less at $6,990 with union scale and $6,001 at non-union scale.

IV. Discussion and Recommendations

Cost estimates of four photovoltaic detailed designs have been presented. The value of the estimates is three-fold. First, cost estimates were provided by General Electric during the original design. Estimating costs is a necessary part of the design process. This report summarizes the last part of a larger project at SNLA to produce and assess a number of designs.

Second, expansion of the cost estimating process has identified areas in which materials non-availability and/or installation impracticability are present. Third, a detailed analysis of the cost drivers identifies areas for further improvement.

Before proceeding further, one must recognize that there are limitations to analyses of this type. The limits are:

(1) The costs might be high due to the assumption of inexperience in the construction industry in handling PV. Thus, the costs might accurately reflect the first unit installed only.

(2) There might be additional inaccuracy due to lack of experience by the A&E firms.

(3) Installation will be done competitively and iteratively. Installation time could be more accurately estimated after a few installations allowing minimizations for markups of unknowns

A. Comparison of Costs

A summary of the cost estimates is presented in Table 13. The total range of installation costs is $1.28/$W_p$ to $2.12/$W_p$ at union wages and $1.22/$W_p$ to $2.19/$W_p$ at non-union wages. No generalization regarding the two estimates was observed, either for overall cost or in terms of breakdowns for labor versus material. In fact, the labor/materials ratio varied from ≈2.3 to ≈3.2 (refer to Section III).

The estimate prepared by Uhl & Lopez shows that the cost of the Southwest residence with battery storage is the highest, although the temperate stand-off mounting case showed the highest $/$W_p$. This emphasizes that there are several interacting factors involved in costing--the mounting scheme, cost of materials, inclusion of storage, etc.

Table 13

INSTALLATION COST ESTIMATE

	UNION				NON-UNION			
	E/E '2000		UHL & LOPEZ		E/E '2000		UHL & LOPEZ	
$\$/W_p$	\$	$\$/W_p$	\$	$\$/W_p$	\$	$\$/W_p$	\$	$\$/W_p$
Southwest	\$ 8,775	\$ 1.45	\$ 8,719	\$ 1.44	\$ 8,453	\$ 1.39	\$ 7,383	\$ 1.22
Southwest with Storage	11,186	1.84	12,644	2.08	10,838	1.79	11,052	1.82
Northeast	6,153	1.50	6,936	1.70	5,923	1.45	6,374	1.56
Southeast	7,186	1.28	8,176	1.46	6,817	1.22	7,197	1.29
Temperate Standoff			9,095	2.12			7,852	1.83
Temperate Integral	9,862	2.29	6,990	1.63	9,440	2.19	6,001	1.40

Two specific observations can be made. Integral and direct mounting schemes appear somewhat comparable in costs. Stand-off mounting is clearly more expensive. Increased labor and materials are involved in the stand-off mount, with the contribution of labor exceeding materials. Battery storage also increases costs. Here, both labor and materials costs are responsible for the increase.

Overall, installation costs for residential-size applications, 3-8 kW_p, range from \$3,000/system to \$16,000/system; or \$1.00 to \$2.00/W_p

B. Design Difficulties

In general, access to the arrays will be limited in all of the cases examined. Some provision will have to be included for installation and maintenance. Some of the aluminum extrusions and elastomers were optimized from the design standpoint and are not production items. The designs do not adequately address air circulation on the roof (outside). Alignment of brackets is critical to proper installation of these systems. The difficultyassociated with alignment will probably require increased installation time and, perhaps, more sophisticated techniques.

C. Recommendations for Further Study

The installation costs contained in this report were estimated based upon detailed designs. Estimated installation costs were also included in the original design process. For comparison, these original estimates were ≈\$7,000/northeast, ≈\$7,500 temperate-integral, ≈\$9,000/southeast, and ≈\$9,500/southwest. The current estimates are in good agreement with the original values.

A remaining question is the lower limit of these installation costs. Recent studies have attempted to reduce installation costs, but the results are not definitive. In a study[8] designed to minimize cost, experienced contractors, economies of scale, and incorporation of mounting hardware (within the modules) were collectively employed. Results from this study showed costs to follow the trend standoff > direct > integral, consistent with the current study. A value of \$0.32 W_p was estimated for array installation in that study. As we have seen in this study, Balance-of-system installation costs can be expected to treble this value to a total of $\approx \$1.00/W_p$--similar to the estimate provided here.

It appears unlikely that there will be much further reduction in the cost of installation It is also likely that any future attempts to reduce cost will not be successful if they are parochial in scope. The mounting technique, the module, module efficiency for the specific mount (thermal effects, snow shedding properties, etc.), reliability, and realistic mark-ups for prime and sub-contractors will all have to be variables for future progress in the area of installation costs.

It appears that a hybrid mount between stand-off and rack--essentially variations of the same technique--would provide minimum intrusion on the roof, allow for cooling on the backside of the modules, be easily maintained, and not be restrictive to house designs. Module installation hardware will eventually be an integral part of the module and the modules will be specifically designed for a predetermined mount. Even though the eventual installation will provide improved systems, it is not clear that much cost reduction will result.

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